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ENGINEERING AND INDUSTRIAL EXPERIMENT STATION

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SPECIAL REPORT

RESULTS OF AN EXPERIMENTAL INVESTIGATION ON DIRECT NUCLEAR PUMPING OF GAS LASERS BY FISSION FRAGMENTS

by

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Abstract

An experiment investigating direct nuclear pumping of a gas laser using argon as lasing medium is described. Results show that light output in form of a directional beam was obtained.

INTRODUCTION

The term "nuclear pumped laser" is used here to refer to a gas laser, excited by nuclear reaction products only and directly, without using any additional electrical, optical or other source for excitation.

The most obvious choice of nuclear reaction products are fission fragments from thermal fission reactions and to a lesser extent protons and tritons from the $He^3(n,p)T$ reaction. Other choices are possible.

The fission fragments, being fast heavy ions are expected to interact with the laser gas in a way that the gas is ionized and excited.

The actual population inversion could be achieved either by excitation caused by fission fragments directly or by electrons, which obtained their energy from the fission fragment in an indirect way.

The problems of obtaining nuclear pumped laser action have been described in a previous publication [1] and shall not be repeated here.

The physics of interaction of fission fragments with the laser gas, has been described by several investigators [2-23]; however, the state of the art is not advanced sufficiently to make it possible either to prove or disprove the possibility of nuclear pumping relying on theoretical consideration only.

In this report an experiment is described which was undertaken with the goal to demonstrate feasibility of nuclear pumping.

EXPERIMENTAL DEVICE

Figure 1 shows the laser cavity, used for the experiment described in this report. The plasma generation section is 91 cm long and consists of a 12-mm O.D. Vycor tube coated on the inside with $U_3^{235}O_8$. The thickness of the U_3O_8 coating was chosen to be about equal to the range of a fission fragment. The cavity is basically a hemispherical configuration, consisting of an optical flat mirror nearly 100 percent reflective from 4500 to 6500 Å and a spherical mirror with a 200-cm radius of curvature and 95 to 99.5 percent reflective from 4500 to 6500 Å. The cavity length of a first device was 199.5 cm, just inside the stability length of such a configuration. This length was used in order to obtain the largest possible volume in the optical cavity. A second device (a modification of the first) had a cavity length of 110 cm and was easier to align and more stable. The cavity shape, design, and spot sizes at critical distances are detailed in Figure 2. The rigid aluminum outer shell is the optical bench for the mirror mounts and the entire structure was placed inside a protective 9-foot tube (1 7/8" O.D. and 1 5/8" I.D.).

The length of this tube was determined by the design of the reactor used for this experiment. It allowed to place the laser cavity between the fuel boxes of the reactor. At this location the cavity was exposed to a neutron flux of about 3×10^{11} n/cm^{2}sec.

Gas pressures of 100-200 torr (argon) were used. An estimate of possible power output from the laser can be made as follows: A neutron

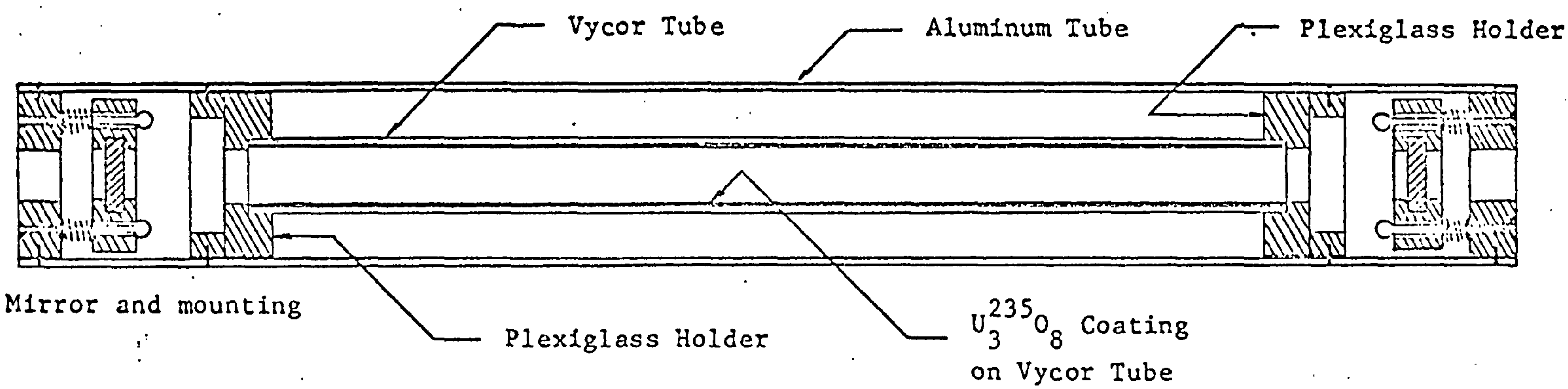
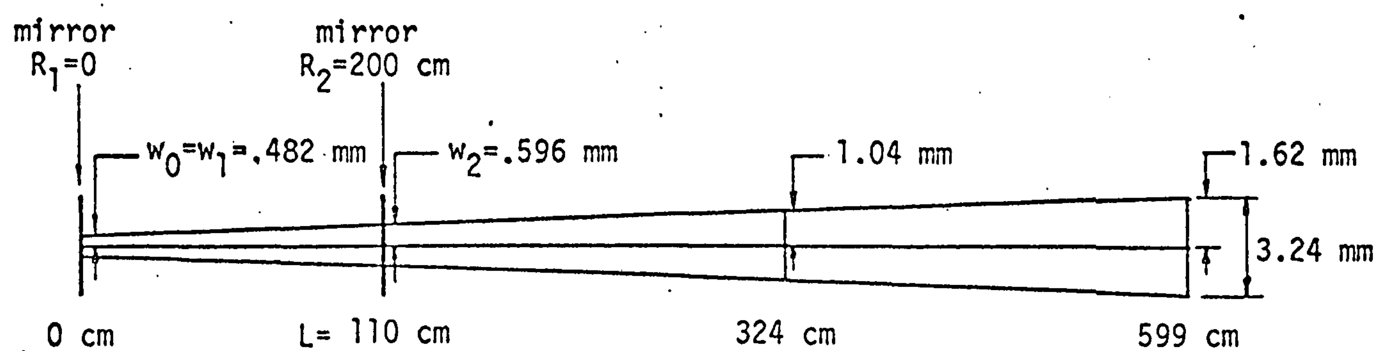


FIGURE 1. SCHEMATIC DIAGRAM OF LASER CAVITY



$$g = 1 - \frac{L}{R_2} \qquad w_1 = w_0 = \sqrt{\frac{L\lambda}{\pi}}\left[\frac{1}{1-g}\right]^{\frac{1}{4}}$$

$$\lambda = 4880\ \mathring{A} \qquad w_2 = \sqrt{\frac{L\lambda}{\pi}}\left[\frac{1}{g(1-g)}\right]^{\frac{1}{4}}$$

FIGURE 2. OPTICAL SCHEMATIC OF LASER CAVITY

flux of 3 x 10^{11} n/cm^2-sec will give a total energy deposition in argon of about 3 x 10^9 MeV/cm^{2}sec assuming a gas pressure of 150 torr. The cylindrical foil has a diameter of 1 cm and a length of 91 cm; therefore, if the total volume could be used as a laser cavity, a power deposition of .137 watts could be expected. For an optical cavity of as small as 4 mm in diameter, a power deposition of 52 milliwatts would be achieved in the cavity. In order to estimate if this would be sufficient to overcome threshold, the following assumption can be made. An α=0.025 gives a free photon lifetime for the cavity t_c=1.2 x 10^{-8} sec. The minimum population inversion required would be 0.75 x 10^8 cm^{-3} (with A = 0.79 x 10^8sec^{-1}). The minimum pumping power would be 35 milliwatts, which compares with 52 milliwatts of power deposition. Since this excess power has to be used to overcome all other losses not included in α=0.025, it is obvious that any output observed would be expected to be minimal.

RESULTS

The laser was placed in thermal column of the University of Florida Training Reactor. At 100 kW reactor power a red glow was seen viewing at a distance of 7 feet. The blue component of the plasma was blocked by the 97 percent reflectivity of the mirror in the blue region. No indication of lasing was seen.

Since the available thermal neutron flux in the thermal column was low over the length of the foil section, the second device (a modification of the cavity length of the first device from 199 cm to 110 cm) was placed in the center vertical port where the neutron flux is much higher (3×10^{11} n/cm^{2}sec). The results at this location were very encouraging.

The following observations were made:

1. A blue-green spot was observable by the eye, but only when the eye was positioned in one exact location.
2. The spot was very bright compared to the hazy blue background. This is quite different than the dim red output observed when the laser was in the thermal column.
3. A phenomenon called "laser speckle," which is seen by the eye and is associated with all visible laser light, was definitely in evidence. This effect is due to the interference fringes around a coherent beam of light.
4. The observable spot was in the blue-green region where the laser output mirror is 97 percent reflective.

5. The photographs in Figure 3 indicate that there was a spot or columnated beam at the 16-foot location. These plates were taken without any lenses or filters between the laser and the film surface. Plate A shows the output at the 7-foot location without the output mirror mounted on the cavity. Plate B shows the output at the same location with the output mirror in place. Plate C is a photograph of the output at the 16-foot position. Note the small spot (circled) with a diameter of 2.5 mm. Plate D was produced at the 16-foot position from a mockup of the laser experiment. A tungsten filament lamp and diffuser replaced the bottom mirror and the top mirror was removed.

The output from the device was decreasing rapidly when Plate C was taken, and a later photograph showed nothing. The spot on Plate C was located in the same position that an observer's eye had to be in order to see the blue-green spot.

If one assumes the device was not lasing, the following items would result:

1. Laser speckle would not be present.
2. The beam at the 16-foot distance would be collimated by the chamber wall dimensions to a spot about 4 in. in diameter (See 3, Plate D).

The output faded so quickly that neither spectroscopic measurements were made, nor coherence or single wave length output could be verified.

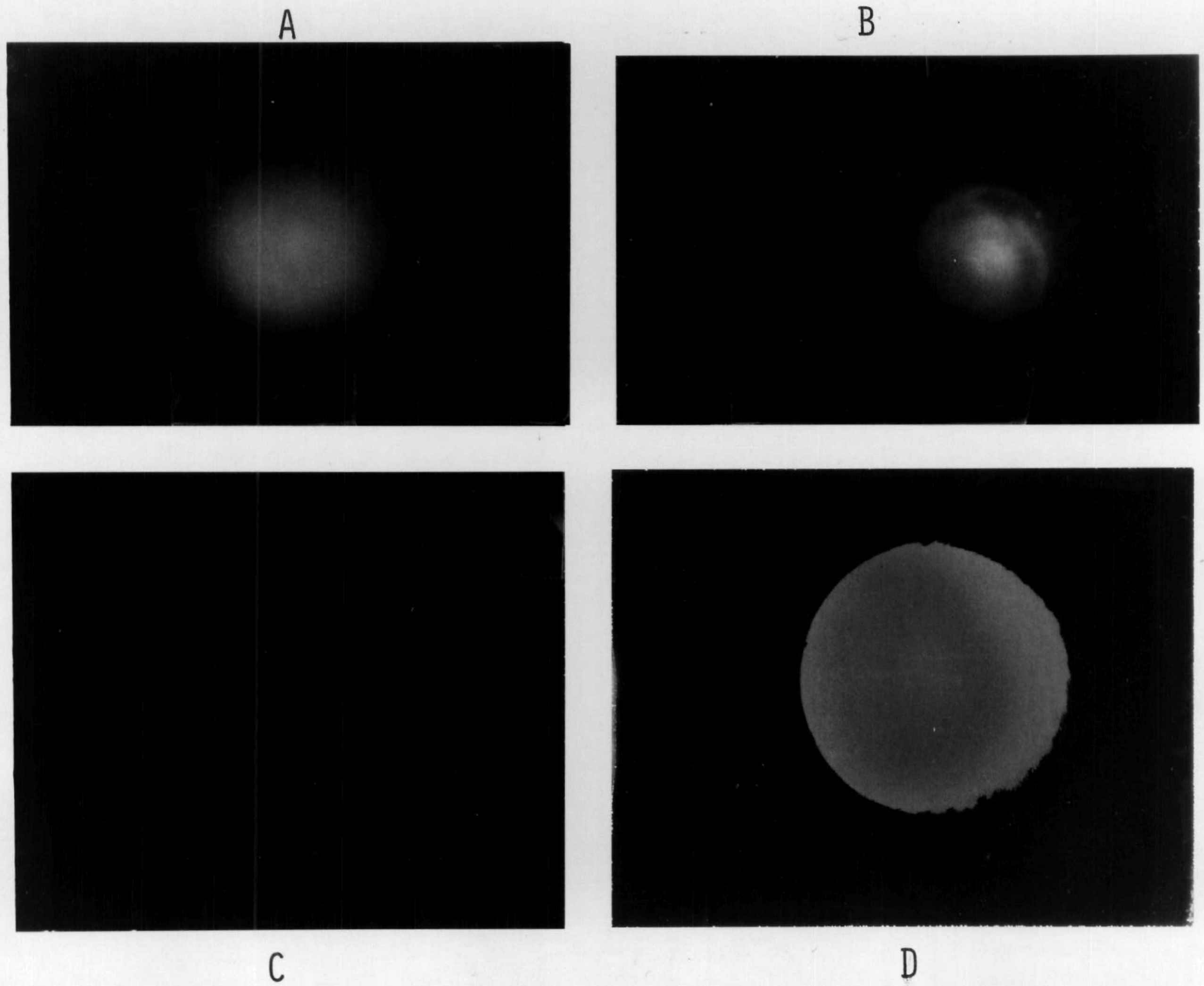


FIGURE 3. PHOTOGRAPHS OF LIGHT OUTPUT (C: SPOT CAUSED BY DIRECTIONAL BEAM AT 16 FOOT DISTANCE)

If lasing is assumed, the spot size at 16 feet (Figure 3) would be approximately 3.24 mm. The spot size on Plate C of Figure 3 is similar in diameter (2.5 mm). Due to the low output of the system the edge of the measured spot may not have been recorded on the film.

Upon removal from the reactor and disassembly of the chamber, the pungent odor from the chamber indicated the breakdown of the small amount of silicone sealer that was used to fix mirror alignment. The output mirror coating had been destroyed, probably by the chemical effects of the silicone sealer products. This explains the loss of photon output.

CONCLUSIONS

An experiment investigating nuclear pumping was performed. Light output from a laser cavity using an argon fill was obtained. The beam obtained was photographed and had a diameter of about 2.5 mm at a location 16-feet from the laser cavity. Since neither gain measurement nor spectroscopic measurement were performed, a claim to have achieved nuclear pumping is not made. However, the observed facts indicate that it is very likely that lasing occurred.

REFERENCES

1. K. Thom and R.T. Schneider, AIAA, Journal 10, 400-406, 1972.

2. Herwig, L.O., "Concepts of Direct Power Conversion of Stored Nuclear Energy to Laser Beam Power," Transactions of the American Nuclear Society, June, 1964.

3. Derr, V.E., et al., "Applications of Nuclear Radiation to the Pumping of Lasers," Proceedings of the 1st Symposium on Radioisotope Applications in Aerospace, Ohio State Univ., 1966.

4. Andriyakhin, V.M., et al., "Increase of CO_2 Laser Power Under the Influence of a Beam of Fast Protons," JETP Letters, Vol. 8, 1968, pp. 214-216.

5. Herwig, L.O., "Summary of Preliminary Studies Concerning Nuclear Pumping of Gas Laser Systems," Rept. C-110053-5, Feb. 1964, United Aircraft, East Hartford, Conn.

6. Russell, G.R., "Feasibility of a Nuclear Laser Excited by Fission Fragments Produced in a Pulsed Nuclear Reactor," Research on Uranium Plasmas, NASA SP-236, 1971.

7. Allario, F. and Schneider, R.T., Enhancement of Laser Output by Nuclear Reactions, NASA SP-236, 1971.

8. Eerkens, J.W. and Cook, R.D., "Research on Direct Nuclear Pumping of Gas Lasers," AF-33(615)-5000, Sept. 1966, Northrop Space Labs., Hawthorne, Calif.

9. Eerkens, J.W. and Rusk, J.R., "Research on Direct Nuclear Pumping of Gas Lasers," AF-33(615)-5000, Jan. 1967, Northrop Space Labs., Hawthorne, Calif.

10. Rusk, J.R., etal., "Research on Direct Nuclear Pumping of Gas Lasers," AFAL-TR, 68-256, 1968, Northrop Space Labs., Hawthorne, Calif.

11. Davis, B.I., and DeJuren, J.A., "Nuclear Pumped Noble Gas Ion Laser Experiments," REPT. NCL-68-13R, 1964, North Carolina State College at Raleigh.

12. DeShong, J.A., "Efficiency of Direction Conversion of Nuclear Energy to Coherent Laser Light," ANL-7110, 1965, Argonne National Lab., Argonne, Illinois.

13. DeShong, J.A., "Optimum Design of High Pressure Large Diameter Direct Nuclear Pumped Gas Lasers," ANL-7030, 1965, Argonne National Lab., Argonne, Ill.

14. DeShong, J.A., "A Carbon Dioxide System for Direct Conversion of Nuclear Energy to Coherent Laser Light," ANL-7210, 1966, Argonne National Lab., Argonne, Ill.

15. DeShong, J.A., "Nuclear Pumped Carbon Dioxide Gas Lasers--Model I Experiments," ANL-7310, 1966, Argonne National Lab., Argonne, Ill.

16. Guyot, J.C., et al., "Experiments Using Nuclear Radiation to Pump a He-Ne Laser," Proceedings of Fifth Annual Review of Electronics, Univ. of Illinois, Urbana, Ill., 1967.

17. Miley, G.H. and Verdeyen, J.T., "Advanced Methods for Nuclear Reactor-Gas Laser Coupling," Interim Report, AEC Contract At(11-1)-2007, 1969, Univ. of Illinois, Urbana, Ill.

18. Guyot, J.C., et al., On Gas Laser Pumping via Nuclear Radiations, NASA SP-236, 1971.

19. Rhoads, H.S. and Schneider, R.T., "Nuclear Enhancement of CO_2 Laser Output," ANS Winter Meeting, Miami, Fla., Oct. 1971.

20. Rhoads, H.S., Schneider, R.T., and Allario, F., "CO_2 Laser Experiments Using Nuclear Reactions as the Ionization Source," 2nd Symposium on Uranium Plasma, Atlanta, Georgia, Nov. 1971.

21. Golubev, S.A. et al., "Effect of Proton Beams on the Generation of a CO_2-Laser" Zh. E Ksp. Teor. Fiz. 62, 458-565 (1972).

22. Andriyakhin, V.M., et al., "High Pressure Gas Laser with Preionization with a Reactor" ZH HTF Pis. Red. 15, No. 11, 637-639 (1972).

23. Ganley, T., J.T. Verdeyn and G.H. Miley, "Enhancement of CO_2 Laser Power and Efficiency by Neutron Irradiation," Appl. Phys. Letters, 18, 568 (1971).